PREDICTION OF THE EVALUATION OF SEMI-ELLIPTICAL DEFECT SHAPE DURING CRACK PROPAGATION

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A review of the different problems relative to crack propagation of semi- elliptical surface crack. The particular following points are examined :

- crack front evolution during propagation of a semi-elliptical surface crack,
- crack front shape evolution during propagation.

A particular attention was given on a semi-elliptical crack in a plate subjected to bending loading.

INTRODUCTION

Propagation of a semi-elliptical crack is oftently observed on the failure surface of engineering structures like pipes, bolts, plates, pressure vessels etc... Several investigators have pointed out that the fatigue propagation of surface flaws in metallic plates are significantly affected by the crack shape change for any kind of loading.

The semi-elliptical form is preserved during the whole growth but the aspect ratio of the part through defects changes (1, 2).

The results from literature show that these flaws tend to follow a common propagation path in the diagram of the crack aspect ratio a/c against the relative crack depth a/t. In the case of plate subjected to a cyclic bending loads the ratio a/c first increases until a maximum and decreases quasi linearly and tends to an asymptote (1 to 10), independent of the initial value of a/c and a/t ratios.

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Several authors have proposed empirical relationships for crack aspect ratio versus relative crack depth which will be shown further. The geometrical evolution of a crack during propagation is relatively complex.

Therefore, the prediction of life duration and fracture conditions need to know the expected evolution of the crack geometry. Several investigations have pointed out that the fatigue propagation of surface cracks in metallic plates are significantly affected by the crack shape change. The semi-elliptical form is preserved during the whole growth, but the aspect ratio of the part through defects changes (figure 1).

CASE OF A PLATE SUBJECTED TO A BENDING LOADING

EXPERIMENTAL STUDY. The material used for the tests is a 35 NCDV 12 steel (French standard) with thermal treatment.

Crack is initiated from a surface notch situated in the middle of the plate. The specimen has a surface of 50x100 mm^2 and a length of 500 mm. Its mechanical characteristics are given in table (1).

TABLE 1- Mechanical characteristics of the 35NCDV12 steel.

yield stress $Re_{0.2}$ [MPa]	ultimate stress Rm [MPa]	elongation A%	toughness K_{IC} [MPa$\sqrt{m}$]
1282	1433	11	103

CRACK FRONT EVOLUTION DURING PROPAGATION OF A SEMI-ELLIPTICAL SURFACE CRACK

Crack front evolution during propagation can be observed on the fracture surface by the shape of the front lines. These lines show the different steps of crack evolution and result from overload during cyclic loading.

A typical example can be seen on figure (2) where the evolution of a surface crack in a steel plate subjected to bending load is easily observed. Boukharouba et al. (1, 2) have analyzed the experimental results of the fatigue crack growth of a surface semi-elliptical crack in a steel plate.

These experiments show that in the case of a plate subjected to a bending load, the evolution of the crack shape is similar to the case of pure tension. Results from tests are reported in figures (3a to 3c).

The crack aspect ratio a/c is plotted versus non dimensional depth a/t. These results are obtained for different initial conditions $(a/c)_{int}$ et $(a/t)_{int}$.

EMPIRICAL EQUATION FOR TENSILE LOADING

Few empirical relationships allowing prediction of the shape of a semi-elliptical defect during propagation are found. Only empirical relationships relative to plate in bending are listed in table (2).

TABLE 2 - Empirical equations for the prediction of the evolution of the ratio a/c, case of bending load

$$\left(\frac{a}{c}\right)_i = \left[1.05 - \left(\frac{a}{t}\right)_i\right] - \left[1 - \left(\frac{a}{t}\right)_i\right]^4 (1.05 - \lambda_P) \quad \text{for } \left(a/t\right)_i \geq D \qquad (1a)$$

Portch* (4)

$$\left(\frac{a}{c}\right)_i = I\left(\frac{a}{t}\right)_i \quad \text{for } \left(\frac{a}{c}\right)_i < D \qquad (1b)$$

$$I = \frac{(a/c)_i}{(a/t)_i} \quad \text{and} \quad D = \frac{3.2 - I}{3(I + 1)} \qquad (1c)$$

Gorner$ (12)

$$\left(\frac{a}{c}\right)_i = \left[1.05\left(\frac{a}{t}\right)_i - \left(\frac{a}{t}\right)_i^2\right]\left\{\left(\frac{a}{t}\right)_i^2 + \lambda_G\left[1.06\left(\frac{a}{t}\right)_i^2\right]\right\}^{-0.5} \qquad (2)$$

Iida & (11)

$$\left(\frac{a}{c}\right)_i = \left[0.85 - 0.75\left(\frac{a}{t}\right)_i\right] \pm 0.0063\left[\left(\frac{a}{t}\right)_i - \lambda_I\right]^{-3.8} \qquad (3)$$

(*) : If D is calculated from equation (1c) to be > 1.0, relationship (1b) is used for the full range of $0 < (a/t)_i < 1.0$. In this case λ_P is calculated from (a) using the initial (a/c) and (a/t) values. If $0 < D < 1.0$, then equation (1b) is used for the range $0 < (a/t)_i < D$.
($) : λ_G is calculated from the initial values of a and c.
(&) : λ_I is a constant calculated using the initial values of a/c and a/t. The plus sign is for $a/c > 0.85 - 0.75\ a/t$ and the minus sign for $a/c < 0.85 - 0.75\ a/t$.

DISCUSSION

We have tried to give some answers about the evolution of the two half-axes of an initially semi-elliptical defect during its propagation and to define its final shape. In the case of a plate subjected to a cyclic bending load or to tension the ratio a/c first increases until a maximum and decreases quasi linearly and tends to an asymptote (2), independent on the initial values of a/c and a/t ratios. We have compared our experimental results to the empirical relationships proposed for bending loading (table 2). A new empirical relationship is proposed in order to fit the experimental results.

$$\left(\frac{a}{c}\right)_i = \left(A + \left(\frac{a}{t}\right)_i\right) - \left(0.0063\left[\left(\frac{a}{t}\right)_i - \lambda_B\right]^{-5.65}\right) \tag{4}$$

A comparison of the prediction of these empirical laws has been established and can be seen in figures (3a and 3b). We can notice that these laws are sensitive to the initial crack aspect ratio.

Tests have allowed direct examination of the crack profile after complete fracture of the specimen. It was observed that the initially elliptical crack front does not preserve the same aspect ratio and that the surface propagation is larger than the deepness one. It is also observed that empirical relationships proposed by Portch (4), Kawahara (6), corrected by Gorner (12) and by Iida (11) do not give accurate predictions according to experimental results obtained for several $(a/c)_{int}$ and $(a/t)_{int}$ ratios.

CONCLUSION

Crack front evolution is generally well predicted by empirical relationships. This evolution is influenced by the loading mode and the fundamental mechanisms are not explained and are probably an example of energy minimization.

Experimental results allowed :

- to verify empirical relationships found in the literature,
- to propose an empirical law which better fits the experimental points, describes and predicts the evolution of different kinds of semi-elliptical defects.

The relationship proposed by Portch (4) is not applicable to all defects and its use does not give good results. The Gorer's one (12), which is simple, well describes the shape of the defect during its evolution, but gives overestimated values. The Iida's one (11) only describes the linear part of the evolution curve. In opposite, the relationship proposed by the authors is derived from that of Iida (11) and fits conveniently the experimental data points for different initial shapes of semi-elliptical defects.

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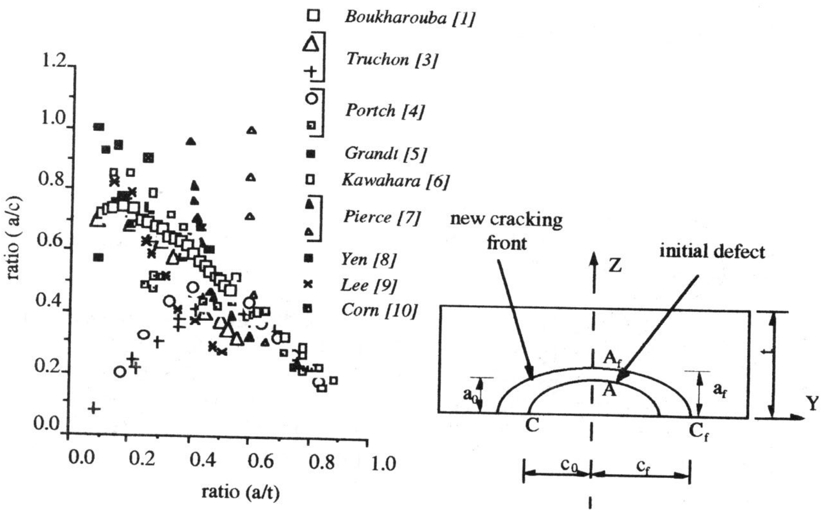
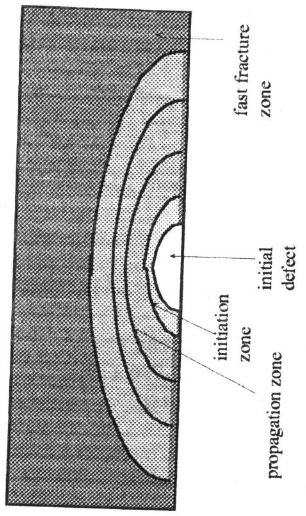


FIGURE 1 : Evolution of crack aspect a/c versus normalized crack depth a/t in bending.



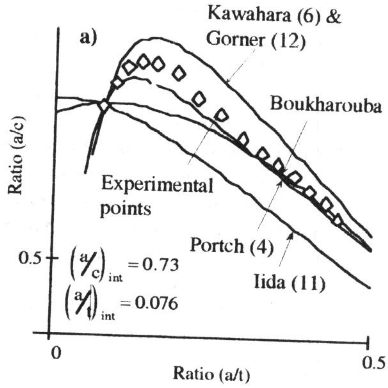
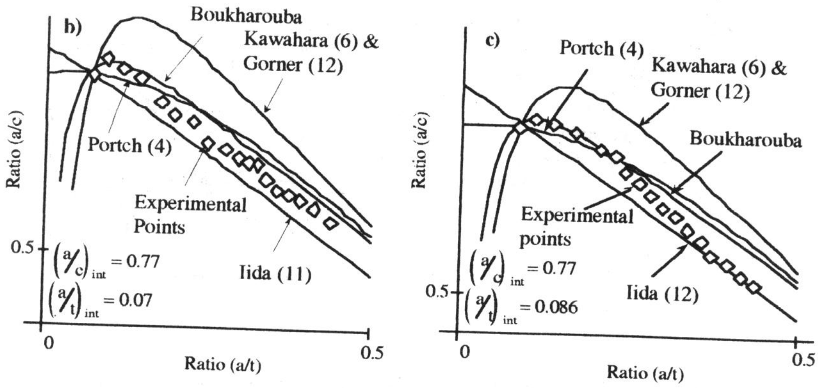


FIGURE 2 : Evolution of crack aspect in a plate submitted to abending loading.



FIGURES 3a - 3c : Crack aspect evolution during crack propagation.